Automated Planning for the Antarctic Mapping Mission

Ben Smith
Jet Propulsion Laboratory
California Institute of Technology
BENJAMIN.D.SMITH@JPL.NASA.GOV

Barbara Engelhardt
Jet Propulsion Laboratory
California Institute of Technology
BARBARA.ENGELHARDT@JPL.NASA.GOV

Darren Mutz
Jet Propulsion Laboratory
California Institute of Technology
DARREN.MUTZ@JPL.NASA.GOV

ABSTRACT

The Second RadarSAT Antarctic Mapping Mission (AMM-2) is scheduled to begin in September of 2000. The Aspen planning system will automate the mission planning process and provide a fast-replanning capability for responding to anomalies during operations. AMM plans consist of several hundred SAR data swaths that must cover a ground region while obeying resource and operational constraints. This paper describes the planning problem, the system architecture, and the planning challenges involved.

KEYWORDS: mission planning, AMM, geometric reasoning.

INTRODUCTION

The Second RadarSAT Antarctic Mapping Mission (AMM-2) is scheduled for execution on September of 2000. This will be similar to the First RadarSAT Antarctic Mapping Mission (AMM-1) executed in 1997. The objective of AMM-1 was to acquire complete coverage of the continent, whereas the objective of AMM-2 is to acquire repeat-pass interferometry to measure ice surface velocity of the outer regions of the continent. The mission objective is to perform a synthetic aperture radar (SAR) mapping of the Antarctic over three consecutive 24-day repeat cycles. The SAR instrument has several "beams" each of which takes data in a rectangular swath. The incidence angle of each beam is separated by a few degrees and partially overlaps the swaths of adjacent beams. The location of the swaths at any given time is determined by the spacecraft orbit. The planning problem is to select a subset of the available swaths that fully cover the Antarctic and satisfy operational and resource constraints imposed by the RadarSAT Mission Management Office (MMO). The driving operational constraints are the limited on-board tape recorder (OBR) capacity and downlink opportunities which constrain the swath subsets that will fit on the OBR between downlinks.

The AMM-1 experience demonstrated that manually developing mission plans was laborious and error-prone. The plans took months to develop, and some constraint violations were not detected until the final MMO review. This required expensive and disruptive last-minute revisions. An automated planner could have quickly identified constraint violations, suggested repairs, and reduced the chance of errors, all of which would have significantly expedited the mission planning process.

Anomalies during AMM-1 operations caused several data takes to be lost. The missing data had to be rescheduled for later in the mission. The new plan had to be submitted within 36 of reacquisition, which meant replan options had to be identified within 8 hours and a final plan submitted within 8 to 72 hours. To manually turn around plans within these time constraints required a team of four people working from pre-generated contingency plan segments. The missed observations were placed into gaps in the original plan to minimize disruptions. More extensive changes were avoided to minimize the planning effort and the chance of introducing errors. Observations that could not be placed in this manner were simply dropped. Automated replanning during operations would allow faster turn-around with fewer people, and enable more extensive changes to the schedule in order to maximize science return.

The rest of this paper describes the automated planning system that is being constructed for AMM-2 based on the Aspen [1,4] planning environment. This system will develop baseline and contingency mission plans and will be used during operations to reschedule observations missed due to anomalies.

AUTOMATED PLANNING SYSTEM

The core planning problem is to select a subset of the available swaths that will cover the Antarctic within the 30 day mission horizon while satisfying all of the OMM constraints. This requires a combination of constraint reasoning, for which planners are well suited, and geometric reasoning for which they are not.

The planning system will operate in two modes: automated and mixed-initiative. In mixed-initiative mode the human user selects the swaths using a coverage analysis tool (SPA or STK) and has Aspen expand them into a detailed plan. The expansion primarily consists of deciding which downlink opportunities to use, tracking resource usage, and verifying adherence to operational constraints. Aspen then reports any constraint conflicts that it cannot resolve without modifying the swaths (e.g., they oversubscribe the on-board recorder). The user modifies the swath selection accordingly and regenerates the plan. This continues until a conflict-free plan is generated. This rapid feedback allows the user to generate a plan much more rapidly than would be possible by hand. The mixed-initiative mode allows the user to use his/her scientific judgement in selecting swaths.

In automated mode Aspen solves the problem automatically. The user provides a set of swath opportunities for each missed observation. Aspen selects at most one opportunity for each observation such that the resulting plan satisfies the operational constraints and recovers as many missed observations as possible. Aspen can be forced to use a specific swaths to recover a given observation by providing only one opportunity. Aspen solves the overall planning problem with a combination of forward dispatch and iterative repair [3,5]. A specialized set-covering algorithm (e.g., [2]) provides a solution to the swath selection problem which guides these two algorithms.

This mode will be used primarily in operations when new plans have to be turned around quickly following anomalies. Anomalies result in missing data takes which must be rescheduled. The user provides Aspen with a set of swaths for the missed observations. This same capability could also support a more aggressive mode where Aspen generates an initial mission plan from scratch, which the user then modifies to meet unarticulated scientific preferences. The user declares that each rectangular region of Antarctica to be imaged is a missed observation, and provides a set of opportunities for each one (this can be done automatically by SPA or STK). Aspen then selects swaths for these missed observations as it would in anomaly replanning.

SYSTEM ARCHITECTURE

The planning system takes as input a set of swath opportunities, downlink opportunities, and a partial plan. The swath opportunities may be fixed so that there is only one swath for each missed observation and Aspen has no swath selection decisions to make, or open so that Aspen must select among several opportunities for each missed observation. The partial plan can force swath-selection and downlink selection decisions, or leave them up to Aspen. This plan is in a spreadsheet format, which the mission planners are most comfortable with. The downlink opportunity file is provided by the MMO, and the user generates the swath opportunities file from a coverage analysis tool (SPA).

The downlink and partial plan files are converted into an Aspen plan file. Aspen expands the partial plan into a complete plan that satisfies the MMO constraints as encoded in the domain model. The model contains external dependency functions that ensure the data-take activities in the plan are consistent with the swaths in the swath opportunities file. The planning algorithm also consults this file to perform swath selection. If there is only one opportunity, the swath selection is trivially solved.

Aspen generates a plan file and a list of conflicts that it was unable to resolve (e.g., because the swaths were fixed and caused conflicts). The plan file is converted into an Excel format that the mission planners prefer, and a list of swaths in SPA format (the

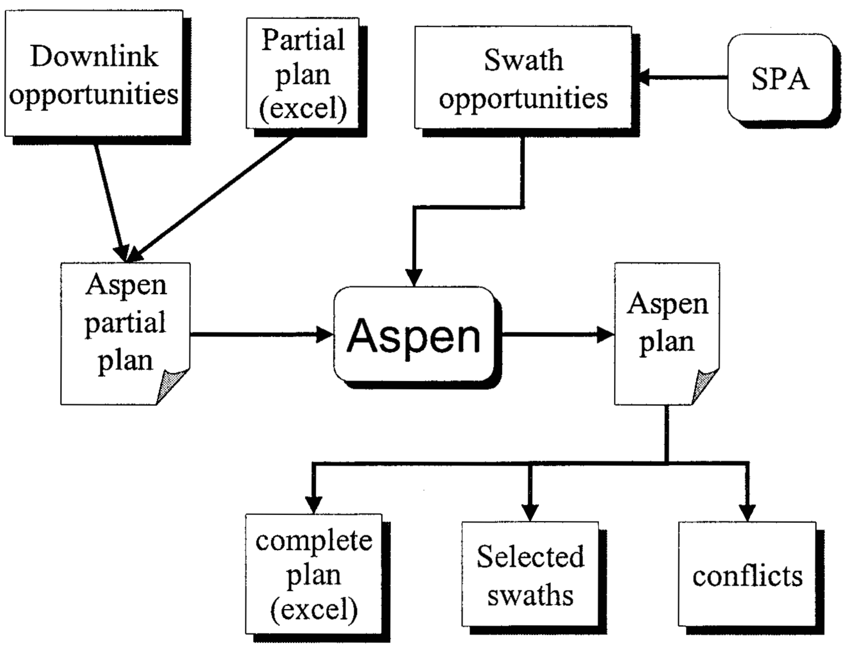

Figure 1: System Data Flow Architecture

swath request format required by the MMO). If the swath opportunities file was fixed, this is a pass-through operation; otherwise it is a down-selection of the original file. It will also generate a swath file in Satellite Tool Kit (STK) format. STK has more powerful coverage analysis capabilities than SPA.

STATUS

The constraint checking capabilities are completed and have been used to generate draft mission plans for submission to the Canadian Space Agency, and will be used to develop more detailed plans in the upcoming months. The planner takes a set of swaths and downlink opportunities as input, assigns the swaths to downlink opportunities, adds supporting activities for each swath and checks the resulting plan for constraint violations. These activities took weeks to perform manually during AMM-1 development, but only minutes with the automated planner. The operational replanning capabilities will be completed by Summer of 2000 for use in the September mission.

ACKNOWLEDGEMENTS

Thanks to John Crawford, the mission architect for AMM-1 and AMM-2, for championing this technology and sharing his knowledge of mission and operational constraints. This paper describes work performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract from the National Air and Space Administration.

REFERENCES

1. Fukunaga, A.; Rabideau, G.; Chien, S.; and Yan, D. "Toward an Application Framework for Automated Planning and Scheduling," in *Proceedings of the 1997 International Symposium on Artificial Intelligence, Robotics, and Automation for Space*, Tokyo, Japan (1997).
2. Garey and Johnson. *Computers and Intractability: A guide to the theory of NP-completeness*. W.H. Freeman and co., New York (1979)
3. Rabideau, Knight, Chien, Fukunaga, and Govindjee, "Iterative Repair Planning for Spacecraft Operations in the ASPEN System" *International Symposium on Artificial Intelligence, Robotics, and Automation for Space (ISAIRAS)*, Noordjwijk, The Netherlands, June 1999.
4. Sherwood et al, "Aspen User's Guide" Technical Document D-15482, Jet Propulsion Laboratory, California Institute of Technology. April, 1999. Also available at http://aspen.jpl.nasa.gov
5. Zweben, M.; Daun, B.; Davis, E.; and Deale M., "Scheduling and Rescheduling with Iterative Repair," in Intelligent Scheduling, Morgan Kaufman, San Francisco (1994).